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FAILURE MECHANISMS OF Ni-H_2 AND Li-ION BATTERIES UNDER HYPERVELOCITY IMPACTS

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ABSTRACT

Introduction

Lithium-Ion (Li-Ion) batteries have yielded significant performance advantages for many industries, including the aerospace industry, and have been selected to replace nickel hydrogen (Ni-H_2) batteries for the International Space Station (ISS) program to meet the energy storage demands. As the ISS uses its vast solar arrays to generate its power, the solar arrays meet their sunlit power demands and supply excess power to battery packs for power delivery on the sun obscured phase of the approximate 90 minute low Earth orbit. These large battery packs are located on the exterior of the ISS, and as such, the battery packs are exposed to external environment threats like naturally occurring meteoroids and artificial orbital debris (MMOD). While the risks from these solid particle environments has been known and addressed to an acceptable risk of failure through shield design, it is not possible to completely eliminate the risk of loss of these assets on orbit due to MMOD, and as such, failure consequences to the ISS have been considered.

Thermal runaway events have been experienced in terrestrial applications of the Li-Ion battery, and have been known to cause a fire that has the potential to spread to neighboring cells. However, many aspects of the impact threat at ISS differ significantly from terrestrial failure scenarios requiring additional studies relevant to the ISS environment. Among the major differences is the configuration that is required for operation in space, the absence of an atmosphere and the impact speeds are far higher at the ISS. Owing to these differences, Li-Ion battery cells, that are representative of those selected for operation on the ISS, have been studied under conditions approximating orbital impacts.

As a basis of comparison of risk, the predecessor nickel-hydrogen (Ni-H_2) cells have also been considered under similar conditions. These comparisons involved impacts where the representative shielding surrounding the battery pack is overwhelmed. This impact study has been directed by the NASA Johnson Space Center Hypervelocity Impact Technology (HVIT) group and performed at the 12.7 mm and 25.4 mm, two-stage, light-gas guns at the Remote Hypervelocity Test Laboratory in NASA Johnson Space Center’s White Sands Test Facility, Las Cruces, NM.

Li-Ion Impact Experiments

Hypervelocity impact conditions on Li-Ion cells are summarized in Table 1. Each test article used two separate Li-Ion battery cells, but only one cell has been targeted. A second cell is included to determine if failure can propagate to a nearby undamaged cell. The impact locations are typically at the terminal end of the battery cells, although some shots to the side of the Li-Ion battery have also been performed. Two different types of Li-Ion batteries have been tested with similar results. When penetrated, the impacted Li-Ion battery typically increases in temperature while the cell contents are ejected. The neighboring cell will in most cases increase in temperature, but only occasionally will the temperature increase substantially which results in failure of the undamaged cell due to thermal runaway. A sequence of images of the Li-Ion battery response from one test is shown in Figure 1. This test resulted in a visible deflagration as the impacted cell contents are energetically ejected over a several second time period following cell penetration. The aluminum honeycomb panel in front of the cell was severely melted due to the expelled cell material; however, the neighboring cell did not transition into thermal runaway.

Ni-H_2 Impact Experiments

The Ni-H_2 cells considered in this testing generates hydrogen gas in the free cell volume as a result of the chemical reactions that occur during charging. The hydrogen accumulates up to a design pressure of 6 MPa which indicates 100% state of charge (SOC) for the rated 81 ampere-hour (Ah). The cells contain an aqueous potassium hydroxide (KOH) electrolyte solution. The cells were proof tested to 10.3 MPa and have a burst pressure of 37.2 MPa. The burst factor for this cell is 6 (burst pressure/operating pressure). In the event of over-pressurization, the cells are designed to leak before burst. Impact testing through an aluminum honeycomb enclosure has been performed to determine if the vessel fragments after penetration and to assess if there are any adverse reactions with the electrode materials, thermal events or cascade failure responses.

Various aluminum and steel projectile diameters have been used in the tests, at impact speeds of 7 km/s and impact angles of 0° and 45° to the normal of the honeycomb panel. None of the tests resulted in fragmentation of the cells. No thermal events or cascading failures resulted to neighboring cells. Generally, the response to cell perforation was that the Ni-H_2 cell vented and the voltage across the terminals declined until the cell could no longer maintain current over a load.

Table 1 Li-Ion cell impact conditions.

Test #	Projectile Diameter (mm)	Impact Obliquity (°)	Impact Speed (km/s)	Cell Damage Measurements (mm)
HITF12143	10.0	0	6.86	Primary cell-Perforated with peak temperature of 184°C Secondary cell-No ignition or thermal runaway
HITF12144	10.0	0	7.02	Primary cell-Perforated, no ignition, peak temperature 194°C Secondary cell- Thermal runaway peaking at 531°C
HITF12145	10.0	30	7.05	Primary cell-No Perforation Secondary cell-No Perforation
HITF12147	13.5	45	6.88	Primary cell-Perforated with peak temperature of 193°C Secondary cell- Thermal runaway peaking at 315°C
HITF12148	10.0	0	7.19	Primary cell-Perforated, no ignition Secondary cell-No ignition or thermal runaway

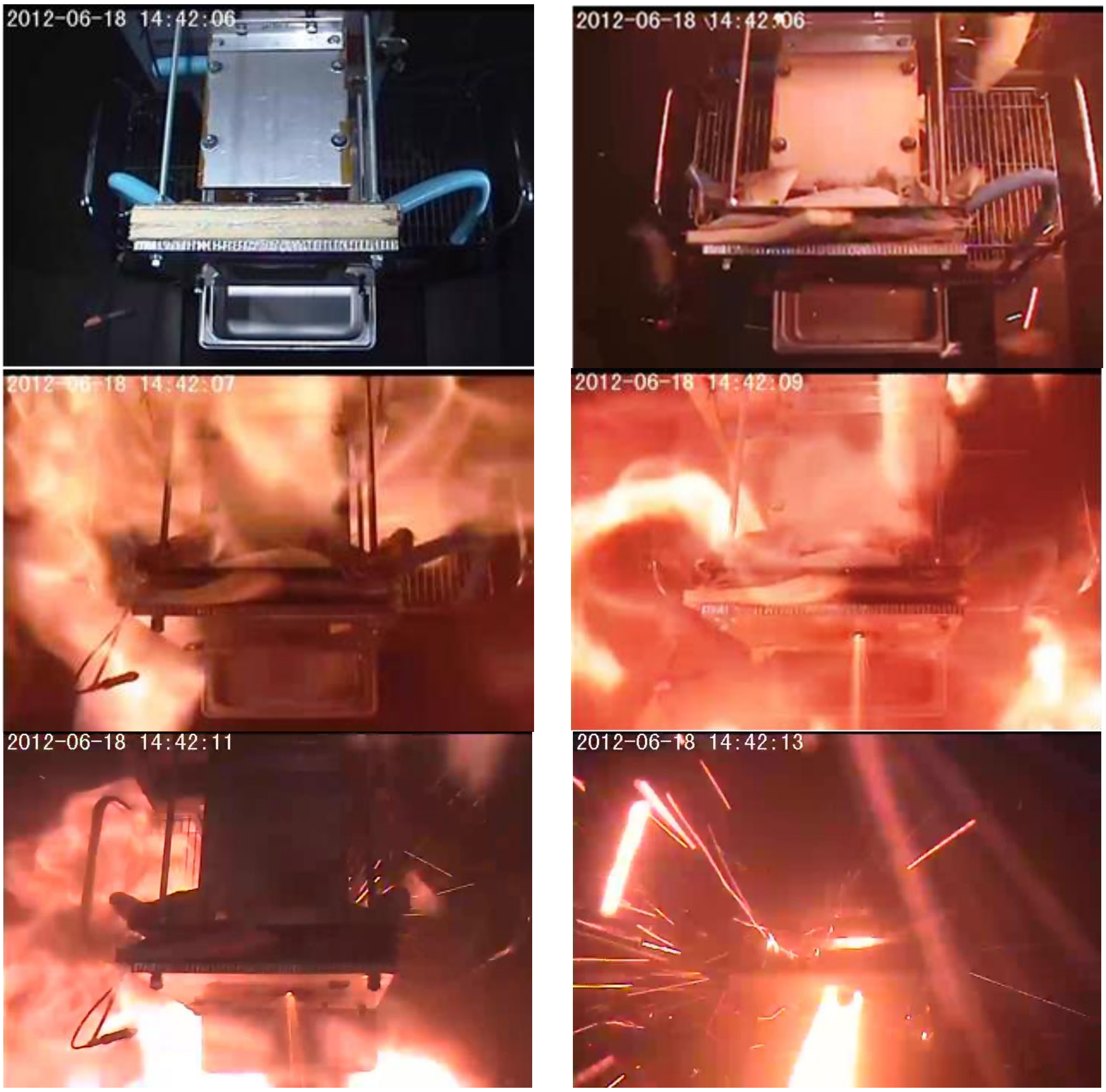

Fig. 1 HITF12143 visible video frames at 1s-2s intervals after impact.